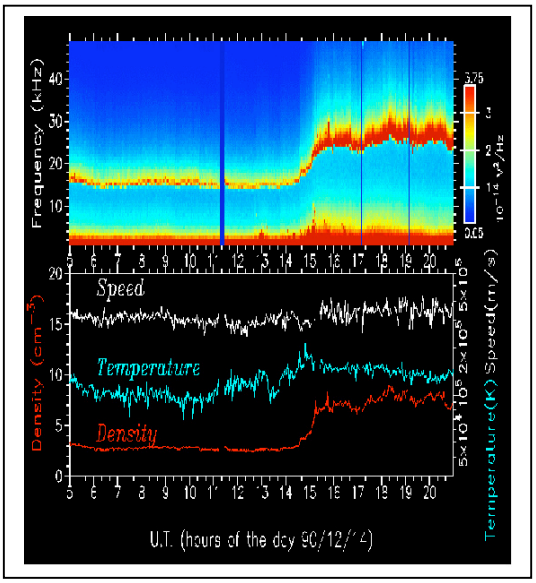
# Solar Wind Graphing and Analysis

**Lesson Plan - Solar Data Plots and Graphing**




## Time:

3 hours

## Objective:

Students will complete activities discovering the correlation between the temperature and speed of solar wind. Students will be able to plot data on a semi-log graph, analyze results from the graph, and then draw conclusions.

## Content Standards:

For grades 7th through 12th (can be adapted to lower grade levels)

K-4:

- Earth and Space Science Standards 2 and 3;
- Science and Technology 2 and 3;
- Physical Science full standard

Grades 5-8:

- Physical Science 2;
- Science as Inquiry 1 and 2
- Science and Technology 1 and 2

Grades: 9-12:

- Science as Inquiry 1 and 2;
- Earth and Space Science Standards 1;
- Science and Technology 1 and 2;
- History and Nature of Science Standards full standard

## Equipment, Materials and Tools:

**For the teacher:**

- Photocopier (for transparencies and copies)
- Overhead projector
- Questions and answers

**For the students:**

- Transparency copy of Figure 6 (semi-log graph worksheet) (one per group or pair)
- Transparency marker (one per group or pair)
- Figure 4 Velocity and Temperature Data Pages (7 pages of various months and days) (one per group or pair)

**Materials to reproduce:**

- Figure 4: Speed and Temperature Data Pages (7 pages of various days in 1999 and 2000)
- Figure 6: (semi-log graph worksheet) make transparency
- Figure 7: Solar Wind Plot (ACE/SWEPAM data Sheet)

**Additional materials for the teacher:**

- Facts for the Teacher: Part I (Auroras)
- Facts for the Teacher: Part II (Multicultural Mythology)

## Procedures:

**PART 1:**

Explain to students the objective of this lesson – the students will learn how to read and analyze solar wind data relayed from a satellite. The students will then graph specific solar wind speeds and temperatures on semi-log graph paper, then analyze and discuss results.

**PART 2:**

A. Hand out copies of Solar Wind Plot - Figure 7 (ACE/SWEPAM data sheet) (one per student)

B. Review and discuss each part of the Plot
(Plot = a measurement of solar wind properties):

- Na/Np = percent of Helium in the solar wind. (More precisely the ratio of Helium to Hydrogen. Note the solar wind is mostly Hydrogen.)
  - N = density,
  - a = alpha particles which are Helium with two electrons removed,
  - p = protons which are Hydrogen with one electron removed.

- Bz (nT) = indicates whether the magnetic field within the solar wind is pointing north or south. If the magnetic field is pointing south it will have a negative charge. When a solar wind has a negative charge, there is a higher chance the solar wind will effect the Earth's system.
  - (nT = nano-tesla, a unit of magnetic field strength)

- Vp = speed of solar wind (this will be plotted on the x-axis of a semi-log graph in part 4 of this lesson)

- Tp = temperature (measured in Kelvin) of solar wind (this will be plotted on the y-axis of a semi-log graph in part 4 of this lesson)

- B (nT) = measures the strength of the magnetic field within the solar wind.

  Np ($cm^{-3}$) = Density of Hydrogen in the solar wind. The number of protons (per unit volume) centimeters

**PART 3:**

A. Hand out Figure 6, transparency of Semi-log Graph Sheet (one per group or pair)

- Guide students in the process of labeling the Semi-log Graph transparency.
  - Instruct the students to title the graph *Solar Wind Temperature and Speed*
  - Instruct students to label the y-axis as *Temperature in Kelvin ($K^0$).* Explain the scientific notation on this y-axis:
    - y-axis starts with 10,000, this represents 1 x $10^4$, each line going up increases, starting with 2 x $10^4$, 3 x $10^4$, 4 x $10^4$ and so on. Thus, 100,000 represents 1 x $10^5$, each line going up increases 2 x $10^5$, 3 x $10^5$, 4 x $10^5$ and so on. 100,000 is 1 x $10^6$.
  - Instruct the students to label the x-axis as *Speed in kilometers per second (km/s)* *Explain* that the x-axis increases in value by 20:
    - *x*-axis starts with 300, each line represents an increase of 20: **300**, 320, 340, 360, 380, **400**, 420, 440, 460, 480, **500** etc.

**PART 4:**

A. Hand out Figure 4: Speed and Temperature Data Pages (one per group or pair)

- Explain to students they are now specifically reading solar wind speed and temperature data from a given day in 1999 or 2000.
- Ask students to look for a possible correlation between speed and temperature.
- Students should work in small groups of 3 or in pairs to complete graph. Each group or pair should be given a different symbol to use to show their solar wind information on the graph (i.e. "+", "x", "**.**", "#", etc.).
- Each group or pair of students should use a different color marker to distinguish data more clearly between each transparency graph.

**PART 5:**

A. After each group has completed the graph, each group or pair will place their completed graph on the overhead.
B. Ask students to locate:
   - the highest temperature,
   - highest speed,
   - lowest temperature, and
   - lowest speed on their graph,
   - have students write it on the board under their year/day (example: 1999/364: highest temperature $3 \times 10^5$).

**PART 6:**

A. After each group or pair has discussed their graph, collect all completed graphs; overlay each graph consecutively on the overhead projector beginning with 1999/364.
B. Ask students if they notice any patterns, similarities, differences, or points of significance. (*Note: This is the vital point in making sure all groups use different color markers when graphing onto transparency)

**PART 7:**

Analysis and conclusions: Questions for reflection

1. Is there a relationship between speed and temperature of solar wind?
   (*Note: This is not an absolute but only a general trend - higher speeds mean higher temperature and lower speeds mean lower temperatures)

2. What deductions can be made with all the graphs put together?

3. What does this pattern tell us?

4. What conclusions can be made after looking at this data?

5. Can you use this graph as a predictive tool when observing solar wind activity?
   (Reminder: This is a general trend not an absolute of how temperature and speed interact with one another, therefore only general predictions can be made from the data on the graph)

6. If the speed of solar wind was 450, what could you predict your temperature to possibly be?
   (Note: Possible answer $7 \times 10^4$)

Materials for Activity:

Figure 1: Solar Wind Spectrogram from ACE

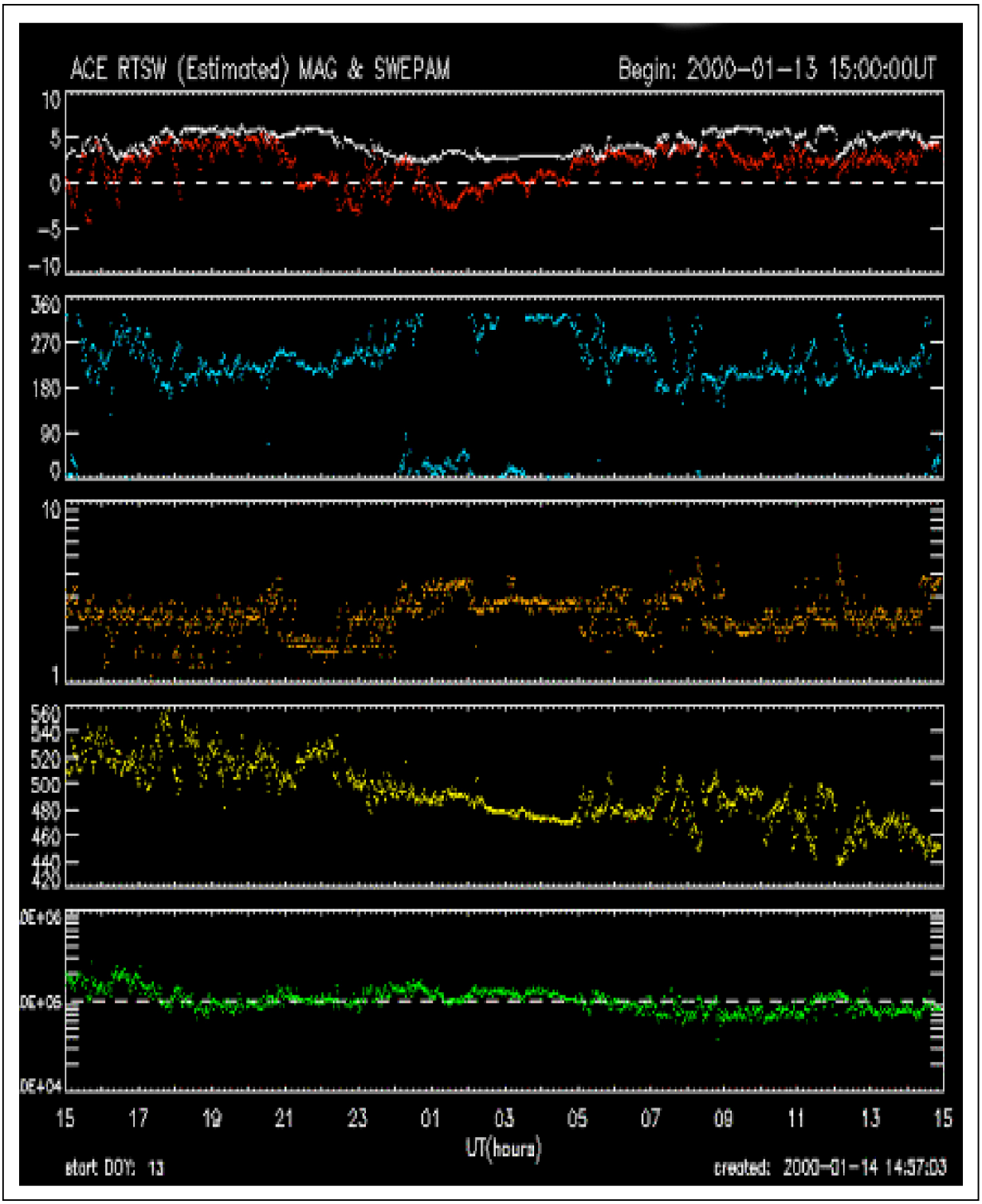


Figure 2: Solar Wind Spectrogram from Genesis

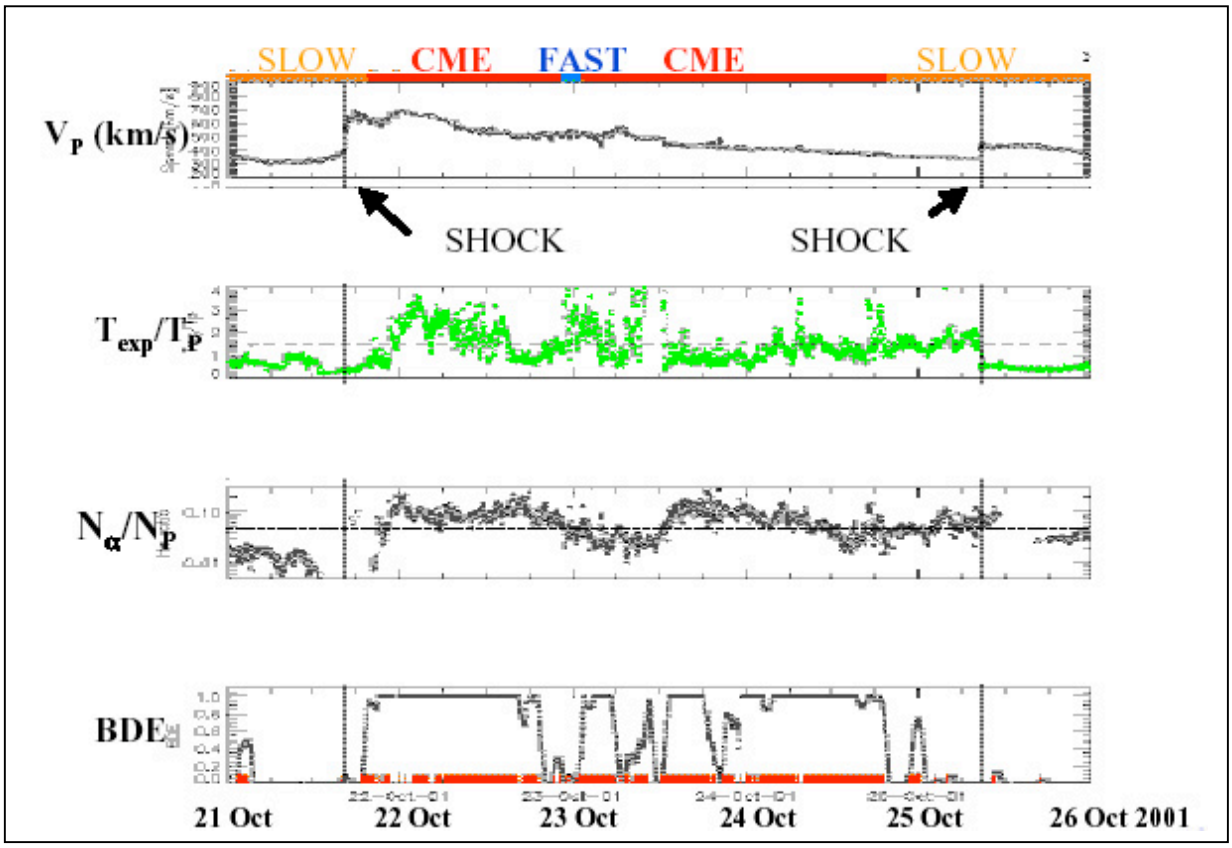


Figure 3: Solar Wind Spectrogram from Ulysses

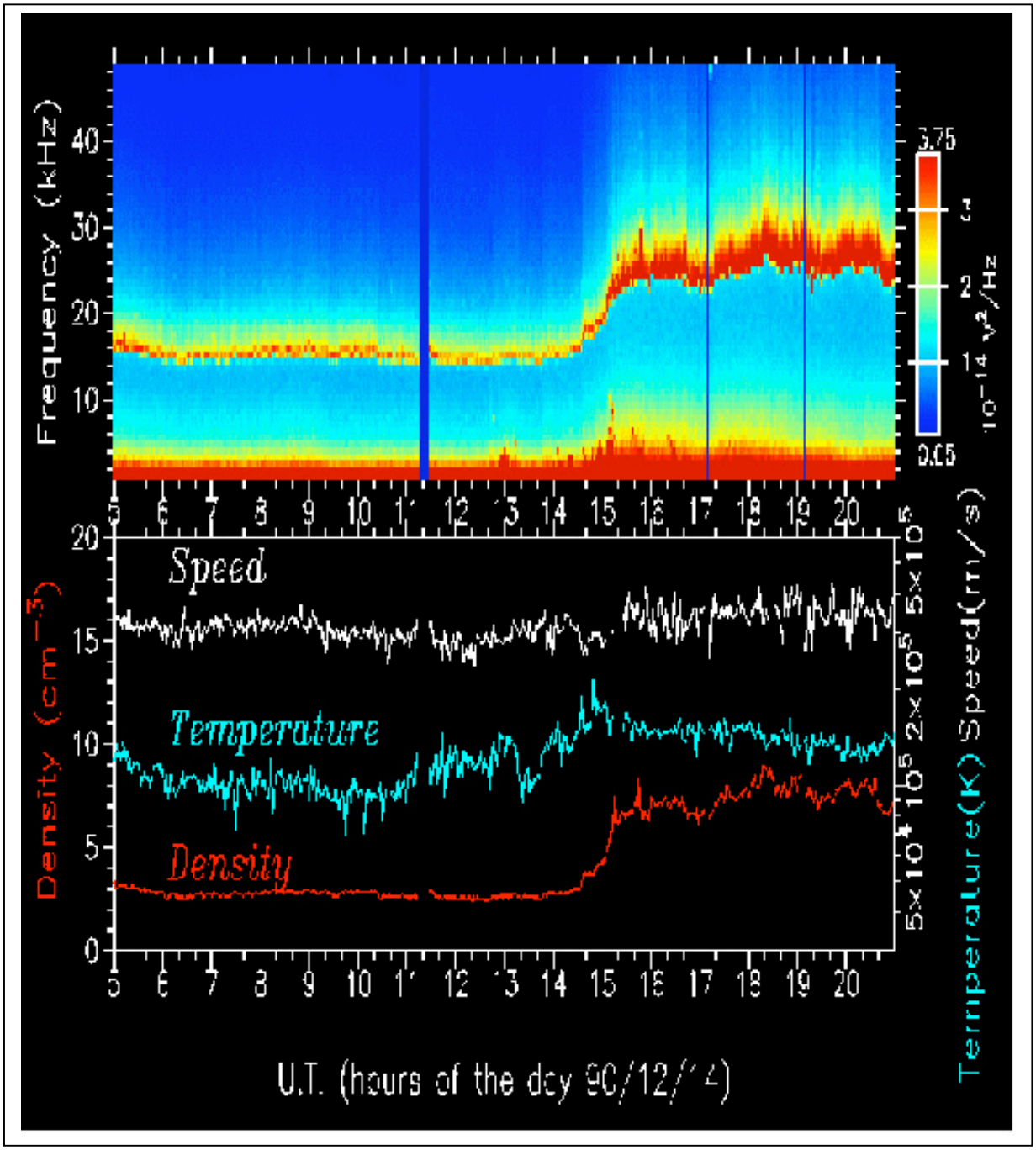


Figure 4: Velocity and Temperature Data (sheet 1)

| Year | DAY/TIME | V | T |
|---|---|---|---|
| 1999 | 364.021 | 370 | 3.9 e+04 |
| 1999 | 364.062 | 370 | 4.5 e+04 |
| 1999 | 364.104 | 380 | 7.0 e+04 |
| 1999 | 364.146 | 380 | 8.9 e+04 |
| 1999 | 364. 187 | 370 | 8.5 e+04 |
| 1999 | 364.229 | 380 | 1.1e +05 |
| 1999 | 364.271 | 380 | 1.2e +05 |
| 1999 | 364.312 | 400 | 1.3e +05 |
| 1999 | 364.354 | 390 | 1.1e +05 |
| 1999 | 364.396 | 390 | 1.1e +05 |
| 1999 | 364.437 | 390 | 9.3e +04 |
| 1999 | 364.479 | 380 | 7.4e +04 |
| 1999 | 364.521 | 390 | 6.5e +04 |
| 1999 | 364.562 | 400 | 5.3e +04 |
| 1999 | 364.604 | 390 | 4.9e +04 |
| 1999 | 364.646 | 390 | 5.4e +04 |
| 1999 | 364.687 | 420 | 7.8e +04 |
| 1999 | 364.729 | 450 | 9.9e +04 |
| 1999 | 364.771 | 550 | 2.3e +05 |
| 1999 | 364.812 | 600 | 3.2e +05 |
| 1999 | 364.854 | 610 | 3.0e +05 |
| 1999 | 364.896 | 650 | 3.7e +05 |
| 1999 | 364.937 | 640 | 4.1e +05 |
| 1999 | 364.979 | 630 | 4.2e +05 |

| Note: DAY/TIME given as Day of year plus fraction of day. |
|---|
| Solar wind speed V in km/s. |
| Solar wind temp. T in K. |

Figure 4: Velocity and Temperature Data (sheet 2)

| year | DAY/TIME | V | T |
|---|---|---|---|
| 1999 | 365.021 | 660 | 4.7e +05 |
| 1999 | 364.062 | 640 | 3.8e +05 |
| 1999 | 365.104 | 650 | 3.3e +05 |
| 1999 | 365.146 | 660 | 4.0e +05 |
| 1999 | 365 .187 | 700 | 4.0e +05 |
| 1999 | 365.229 | 660 | 3.1e +05 |
| 1999 | 365.271 | 660 | 2.9e +05 |
| 1999 | 365.312 | 680 | 3.2e +05 |
| 1999 | 365.354 | 660 | 3.1e +05 |
| 1999 | 365.396 | 670 | 3.2e +05 |
| 1999 | 365.437 | 630 | 2.2e +05 |
| 1999 | 365.479 | 620 | 2.2e +05 |
| 1999 | 365.521 | 620 | 2.2e +05 |
| 1999 | 365.562 | 640 | 2.3e +05 |
| 1999 | 365.604 | 650 | 2.7e +05 |
| 1999 | 365.646 | 650 | 2.7e +05 |
| 1999 | 365.687 | 630 | 2.2e +052.4e +05 |
| 1999 | 365.729 | 640 | 1.9e +052. |
| 1999 | 365.771 | 640 | 3.6e +05 |
| 1999 | 365.812 | 650 | 2.9e +05 |
| 1999 | 365.854 | 670 | 2.8 e+05 |
| 1999 | 365.896 | 690 | 3.6 e+05 |
| 1999 | 365.937 | 670 | 2.9 e+05 |
| 1999 | 365.979 | 670 | 3.0 e+05 |
| | | | |
| Note: DAY/TIME given as Day of year plus fraction of day. | | | |
| Solar wind speed V in km/s. | | | |
| Solar wind temp. T in K. | | | |

Figure 4: Velocity and Temperature Data (sheet 3)

| Year | DAY/TIME | V | T |
|---|---|---|---|
| 2000 | 1.021 | 670 | 2.5 e+05 |
| 2000 | 1.062 | 700 | 2.8 e+05 |
| 2000 | 1.104 | 710 | 3.1 e+05 |
| 2000 | 1.146 | 720 | 3.5 e+05 |
| 2000 | 1.187 | 710 | 3.6 e+05 |
| 2000 | 1.229 | 720 | 3.4 e+05 |
| 2000 | 1.271 | 750 | 3.4 e+05 |
| 2000 | 1.312 | 760 | 3.4 e+05 |
| 2000 | 1.354 | 750 | 2.8 e+05 |
| 2000 | 1.396 | 770 | 2.6 e+05 |
| 2000 | 1.437 | 730 | 2.4 e+05 |
| 2000 | 1.479 | 730 | 2.3 e+05 |
| 2000 | 1.521 | 740 | 2.2 e+05 |
| 2000 | 1.563 | 730 | 2.0 e+05 |
| 2000 | 1.604 | 720 | 2.0 e+05 |
| 2000 | 1.646 | 720 | 1.8 e+05 |
| 2000 | 1.688 | 710 | 1.9 e+05 |
| 2000 | 1.729 | 710 | 1.8 e+05 |
| 2000 | 1.771 | 740 | 2.2 e+05 |
| 2000 | 1.813 | 720 | 2.1 e+05 |
| 2000 | 1.854 | 710 | 1.8 e+05 |
| 2000 | 1.896 | 720 | 1.7 e+05 |
| 2000 | 1.938 | 700 | 1.9 e+05 |
| 2000 | 1.979 | 700 | 1.9 e+05 |

| Note: DAY/TIME given as Day of year plus fraction of day. |
|---|
| Solar wind speed V in km/s. |
| Solar wind temp. T in K. |

Figure 4: Velocity and Temperature Data (sheet 4)

| Year | Date/Time | V | Temp |
|---|---|---|---|
| 2000 | 2.021 | 700 | 1.9 e+05 |
| 2000 | 2.063 | 700 | 1.9 e+05 |
| 2000 | 2.104 | 690 | 1.8 e+05 |
| 2000 | 2.146 | 680 | 1.7 e+05 |
| 2000 | 2.188 | 690 | 1.7 e+05 |
| 2000 | 2.229 | 690 | 1.9 e+05 |
| 2000 | 2.271 | 670 | 1.9 e+05 |
| 2000 | 2.313 | 670 | 1.9 e+05 |
| 2000 | 2.354 | 660 | 1.9 e+05 |
| 2000 | 2.396 | 660 | 1.8 e+05 |
| 2000 | 2.438 | 670 | 2.1 e+05 |
| 2000 | 2.479 | 680 | 2.4 e+05 |
| 2000 | 2.521 | 710 | 2.4 e+05 |
| 2000 | 2.563 | 660 | 2.0 e+05 |
| 2000 | 2.604 | 660 | 2.1 e+05 |
| 2000 | 2.646 | 690 | 1.9 e+05 |
| 2000 | 2.688 | 680 | 2.1 e+05 |
| 2000 | 2.729 | 680 | 1.6 e+05 |
| 2000 | 2.771 | 670 | 1.4 e+05 |
| 2000 | 2.813 | 680 | 2.0 e+05 |
| 2000 | 2.854 | 670 | 1.9 e+05 |
| 2000 | 2.896 | 670 | 1.8 e+05 |
| 2000 | 2.938 | 660 | 1.3 e+05 |
| 2000 | 2.979 | 670 | 1.1 e+05 |

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| Note: DAY/TIME given as Day of year plus fraction of day. |
| Solar wind speed V in km/s. |
| Solar wind temp. T in K. |

Figure 4: Velocity and Temperature Data (sheet 5)

| Year | DAY/TIME | V | T |
|---|---|---|---|
| 2000 | 3.021 | 650 | 1.2 e+05 |
| 2000 | 3.063 | 620 | 1.0 e+05 |
| 2000 | 3.104 | 630 | 1.1 e+05 |
| 2000 | 3.146 | 620 | 1.1 e+05 |
| 2000 | 3.188 | 620 | 1.4 e+05 |
| 2000 | 3.229 | 610 | 1.3 e+05 |
| 2000 | 3.271 | 600 | 1.3 e+05 |
| 2000 | 3.313 | 590 | 1.4 e+05 |
| 2000 | 3.354 | 590 | 1.7 e+05 |
| 2000 | 3.396 | 590 | 1.5 e+05 |
| 2000 | 3.438 | 600 | 1.5 e+05 |
| 2000 | 3.479 | 590 | 1.4 e+05 |
| 2000 | 3.521 | 580 | 1.1 e+05 |
| 2000 | 3.563 | 560 | 1.3 e+05 |
| 2000 | 3.604 | 540 | 1.3 e+05 |
| 2000 | 3.646 | 550 | 9.5 e+04 |
| 2000 | 3.688 | 540 | 1.0 e+05 |
| 2000 | 3.729 | 550 | 1.2 e+05 |
| 2000 | 3.771 | 540 | 1.5 e+05 |
| 2000 | 3.813 | 580 | 1.7 e+05 |
| 2000 | 3.854 | 570 | 1.9 e+05 |
| 2000 | 3.896 | 570 | 1.7 e+05 |
| 2000 | 3.938 | 590 | 1.5 e+05 |
| 2000 | 3.979 | 590 | 1.6 e+05 |

| Note: DAY/TIME given as Day of year plus fraction of day. |
|---|
| Solar wind speed V in km/s. |
| Solar wind temp. T in K. |

Figure 4: Velocity and Temperature Data (sheet 6)

| Year | DAY/TIME | V | T |
|---|---|---|---|
| 2000 | 4.021 | 590 | 1.5 e+05 |
| 2000 | 4.062 | 590 | 1.6 e+05 |
| 2000 | 4.104 | 590 | 1.5 e+05 |
| 2000 | 4.146 | 590 | 1.4 e+05 |
| 2000 | 4.187 | 600 | 1.4 e+05 |
| 2000 | 4.229 | 600 | 1.6 e+05 |
| 2000 | 4.271 | 590 | 1.6 e+05 |
| 2000 | 4.312 | 600 | 1.5 e+05 |
| 2000 | 4.354 | 630 | 2.5 e+05 |
| 2000 | 4.396 | 630 | 2.4 e+05 |
| 2000 | 4.437 | 600 | 1.5 e+05 |
| 2000 | 4.479 | 600 | 1.3 e+05 |
| 2000 | 4.521 | 590 | 1.6 e+05 |
| 2000 | 4.562 | 580 | 1.8 e+05 |
| 2000 | 4.604 | 560 | 1.8 e+05 |
| 2000 | 4.646 | 570 | 1.2 e+05 |
| 2000 | 4.687 | 570 | 1.0 e+05 |
| 2000 | 4.729 | 530 | 1.0 e+05 |
| 2000 | 4.771 | 550 | 9.5 e+04 |
| 2000 | 4.812 | 560 | 8.6 e+04 |
| 2000 | 4.854 | 540 | 9.9 e+04 |
| 2000 | 4.896 | 510 | 1.1 e+05 |
| 2000 | 4.937 | 520 | 9.8 e+04 |
| 2000 | 4.979 | 520 | 1.2 e+05 |

| Note: DAY/TIME given as Day of year plus fraction of day. |
|---|
| Solar wind speed V in km/s. |
| Solar wind temp. T in K. |

Figure 4: Velocity and Temperature Data (sheet 7)

| Year | DAY/TIME | V | T |
|---|---|---|---|
| 2000 | 5.021 | 530 | 8.3 e+04 |
| 2000 | 5.062 | 520 | 7.2 e+04 |
| 2000 | 5.104 | 540 | 7.8 e+04 |
| 2000 | 5.146 | 510 | 9.8 e+04 |
| 2000 | 5.187 | 510 | 9.5 e+04 |
| 2000 | 5.229 | 520 | 9.3 e+04 |
| 2000 | 5.271 | 510 | 1.3 e+05 |
| 2000 | 5.312 | 520 | 1.4 e+05 |
| 2000 | 5.354 | 540 | 1.1 e+05 |
| 2000 | 5.396 | 520 | 1.1 e+05 |
| 2000 | 5.437 | 510 | 1.3 e+05 |
| 2000 | 5.479 | 510 | 1.5 e+05 |
| 2000 | 5.521 | 520 | 1.4 e+05 |
| 2000 | 5.562 | 520 | 1.6 e+05 |
| 2000 | 5.604 | 530 | 1.5 e+05 |
| 2000 | 5.646 | 520 | 1.6 e+05 |
| 2000 | 5.687 | 510 | 1.6 e+05 |
| 2000 | 5.729 | 520 | 1.6 e+05 |
| 2000 | 5.771 | 530 | 1.4 e+05 |
| 2000 | 5.812 | 540 | 1.1 e+05 |
| 2000 | 5.854 | 520 | 1.7 e=05 |
| 2000 | 5.896 | 520 | 1.5 e+05 |
| 2000 | 5.937 | 510 | 1.5 e+05 |
| 2000 | 5.979 | 520 | 1.3 e+05 |

| Note: DAY/TIME given as Day of year plus fraction of day. |
|---|
| Solar wind speed V in km/s. |
| Solar wind temp. T in K. |

Figure 5: ACE/SWEPAM graph

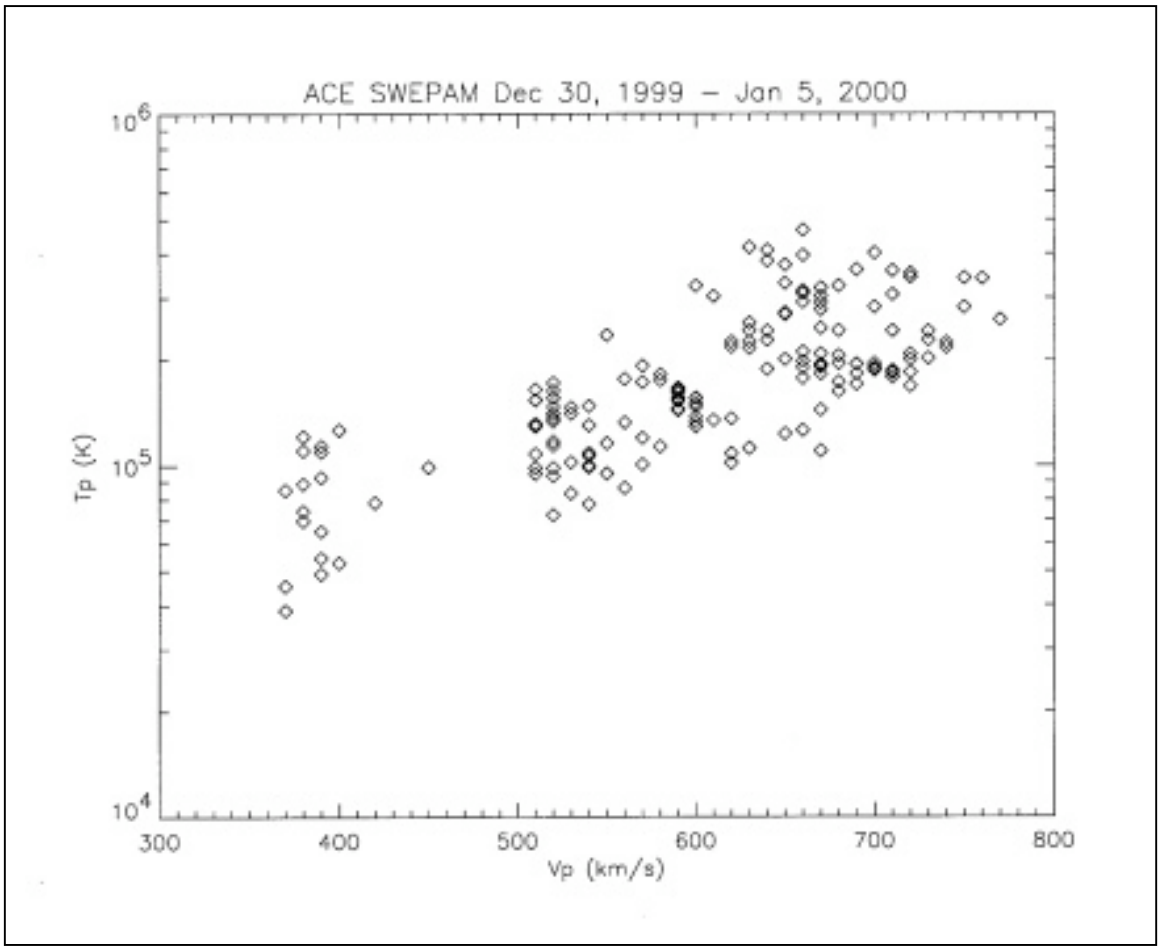


Figure 6: Semi-log Graph Paper

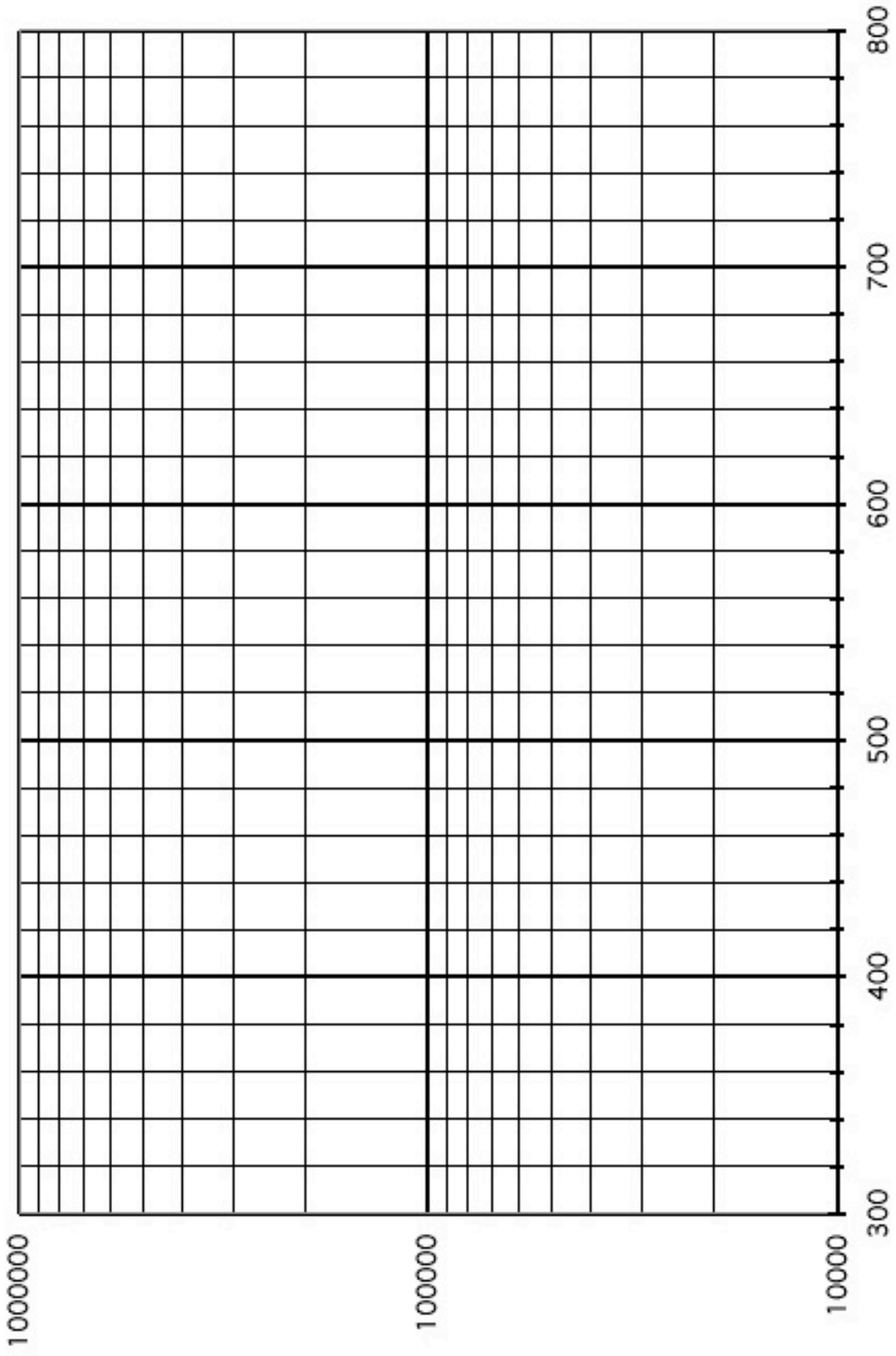
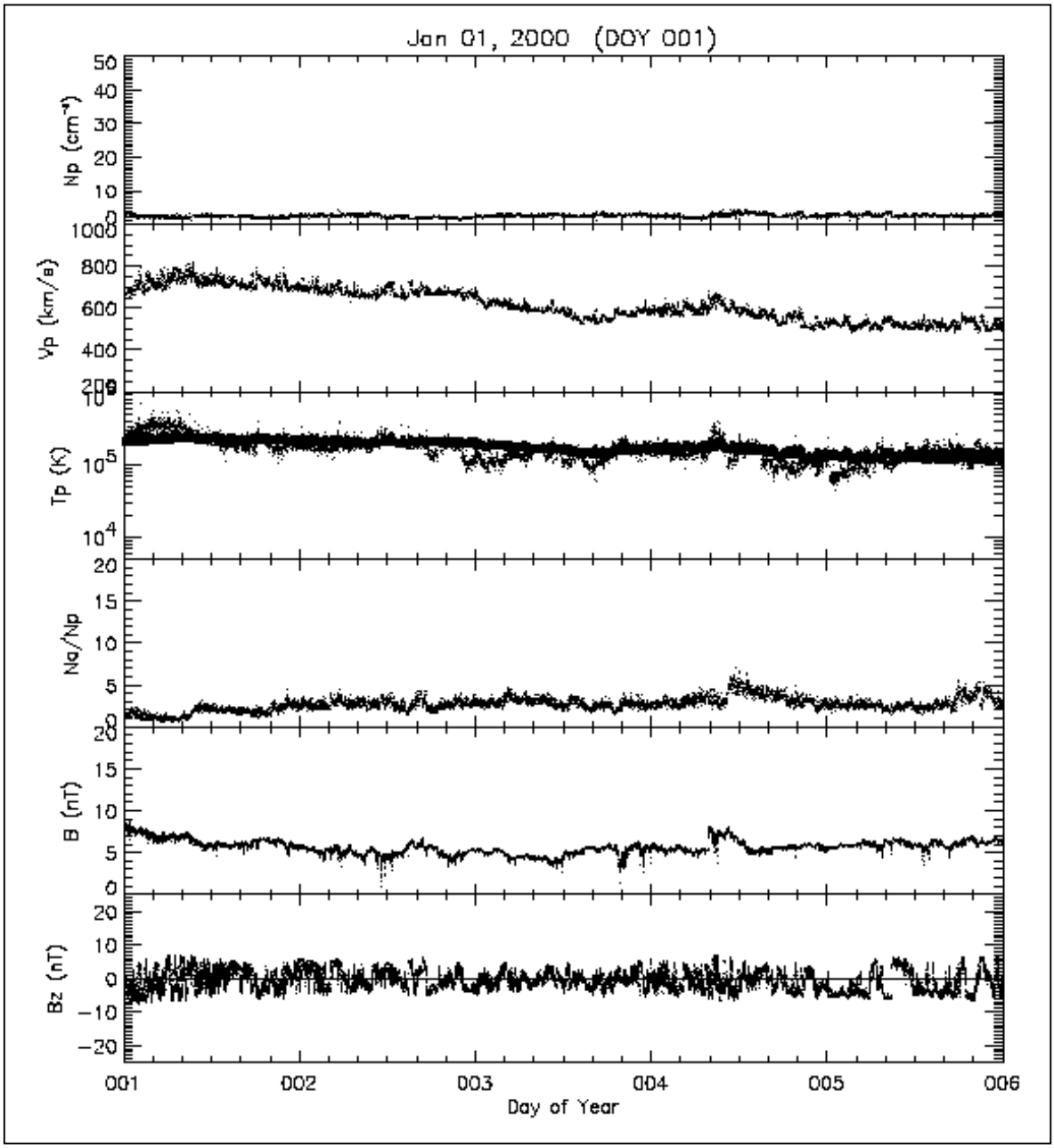


Figure 7: ACE/SWEPAM Data Sheet



**Assessment:**

- Can the student complete the plots on graph in a small group or pair?
- Did the student participate in class discussion or ask questions?
- Can the student take a short quiz and/or complete worksheet of questions on solar wind graphing and analysis?
- Ask students to write a paragraph on how temperature and speed of solar wind interact with each other.
- Ask students to make journal entries during the lesson.

Teacher Key to Student Worksheet: **Solar Wind Graphing and Analysis Questions:**

Name: _____ Period: _____ Date: _____

Teacher note: The following questions and answers can be used to build background for teachers or to explore prior knowledge and facilitate discussions with students.

1. What is solar wind?
   - Solar wind is charged particles emitted from the Sun. Answers will vary-the teacher can expand as necessary.
2. What is the measure of a moderate solar wind storm? A major storm?
   - The measurements of moderate and major storms will vary depending on the data sheets.
3. What effect does temperature have on increasing speed?
   - Usually the higher the temperature, the higher the speed.
4. How is the magnitude of the solar wind measured?
   - Instruments on satellites collect solar wind samples.
5. Why is the temperature in Kelvin and not Celsius?
   - Kelvin ($K^0$) is the unit used for high temperatures in the scientific community.
6. What are the units that define velocity?
   - Kilometers/second (km/s) are the units used to define velocity.

Matching:

| | |
|---|---|
| 1. __e__ B | a. measures whether the magnetic field within the solar wind is pointing north or south |
| 2. __h__ Na/Np | b. nano-tesla |
| 3. __a__ Bz | c. speed |
| 4. __g__ T | d. horizontal (plane of graph) |
| 5. __b__ nT | e. strength of magnitude of solar wind |
| 6. __c__ V | f. vertical (plane of graph |
| 7. __d__ *x*-axis | g. temperature in Kelvin |
| 8. __f__ y-axis | h. percent of helium in solar wind |

Student Worksheet: **Solar Wind Graphing and Analysis Questions:**

Name: _____ Period: _____ Date: _____

1. What is solar wind?

2. What is the measure of a moderate solar wind storm? A major storm?

3. What effect does temperature have on increasing speed?

4. How is the magnitude of the solar wind measured?

5. Why is the temperature in Kelvin and not Celsius?

6. What are the units that define velocity?

Matching:

| | |
|---|---|
| 1. _____ B | a. measures whether the magnetic field within the solar wind is pointing north or south |
| 2. _____ Na/Np | b. nano-tesla |
| 3. _____ Bz | c. speed |
| 4. _____ T | d. horizontal (plane of graph) |
| 5. _____ nT | e. strength of magnitude of solar wind |
| 6. _____ V | f. vertical (plane of graph |
| 7. _____ *x*-axis | g. temperature in Kelvin |
| 8. _____ y-axis | h. percent of helium in solar wind |